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ENGINEERING DESIGN OF REFUSE INCINERATORS. A MANUAL PREPARED FOR THE NATIONAL PARK SERVICE

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U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
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NATIONAL PARK SERVICE

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U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Bureau of State Services
Division of Sanitary Engineering Services
General Engineering Program

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Page 24: Ibid, Reference #7.

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PREFACE

The sanitary disposal of refuse is important to the maintenance of a healthful environment for the millicns of visitors to the national parks each year. Incineration is a method of refuse disposal which has application in many areas administered by the National Park Service. Mr. Paul McG Miller, Chief Engineer, National Park Service, requested that the Public Health Service prepare this manual to provide a guide to engineers concerned with the design of waste disposal installations within the various parks.

The basic data on refuse quantity, composition, and peculiar park conditions used herein were taken from the report "Refuse Sanitation in the National Parks" prepared by this office for the National Park Service in 1955. Acknowledgment is due to several National Park Service, Public Health Service, State Health Department, and Consulting Engineer personnel for review and suggestions on the preliminary draft of the manual.

The manual was prepared by Mr. Roy Martin, Assistant Sanitary Engineer, under the general guidance of Mr. Arthur H. Neill, Chief, Technical Services Section, and Mr. Leo Weaver, former Chief, Refuse Sanitation Unit of the General Engineering Program. Mr. Andrew Rose, Chief, Engineering Research and Development Section, Air Pollution Program, Robert A. Taft Sanitary Engineering Center, was particularly helpful in the preparation of the section on design which reflects current knowledge for meeting applicable community air pollution control requirements.

Malcolm C. Hope, Chief
General Engineering Program
Division of Sanitary Engineering Services

PART I

INTRODUCTION

This manual is a guide for National Park Service personnel to assist them in preparing specifications for, and the engineering design of, refuse incinerators. It should be useful also to other agencies who find that incineration offers a solution to their refuse disposal problems.

It is assumed that an engineering survey has been made and that incineration has been chosen over sanitary landfill, or a modified sanitary landfill, due to nuisances from wild animals, a rocky terrain, or the inability to find sufficient land. It is further assumed that this survey has indicated that it would be too costly, or inconvenient, to make use of a local or municipal system.

PART II

FACTORS INFLUENCING THE DESIGN OF A REFUSE INCINERATOR

1. Definitions

Ashes	The residue from the burning of combustible materials and the non-combustible portion of the refuse charged into an incinerator.
Auxiliary Fuel	Fuel, other than the combustible refuse, used to supply auxiliary heat for initial ignition and/or to maintain proper temperatures in an incinerator.
British Thermal Unit (BTU)	The quantity of heat required to raise one pound of water $1^{o}F$.
Fly Ash	Particulate matter; finely divided solid particles in the gases leaving an incinerator furnace.
Furnace	Primary chamber; ignition chamber; chamber in which the raw refuse dries and burns.
Garbage	Putrescible animal and vegetable wastes resulting from the handling, preparation, cooking, and serving of food.
Heating Value	The number of BTU's released when one pound of fuel is burned to completion.
Mixing Chamber	Chamber in which volatile gases mix and burn for the purpose of relieving odor and toxicity. (See Secondary Combustion Chamber).
Mol	That quantity of a substance in pounds numerically equal to its molecular weight.
Refuse	All putrescible and nonputrescible solid wastes (except body wastes) including garbage, rubbish, ashes, and dead animals.

Rubbish	Nonputrescible solid wastes (excluding ashes) consisting of both combustible wastes such as paper, cardboard, yard clippings, and wood; and noncombustible wastes such as tin cans, glass and crockery.
Secondary Combustion Chamber	Expansion chamber; chamber in which combustion gases expand and burn out, and fly ash settles. Sometimes this chamber, instead of being separated from the mixing chamber, is part of the mixing chamber.

2. Site Selection

When incineration has been chosen as the method of refuse disposal, the selection of a proper site for the incinerator plant is important. Since conditions in different parks are variable, it is difficult to specify site requirements for all. Economy and appearance are important considerations. If possible, an inconspicuous location central to collection areas and easily accessible by road is desirable. A ramp is necessary for reaching the charging floor of a direct charge plant, therefore, a side hill site would be worth looking for to reduce construction cost.

Care should be taken to avoid a location where a down draft of the stack effluent is caused by the prevailing wind. A bank of high trees in the vicinity may cause stack discharge depressions; or the same effect might be had from the proximity of a hill or ravine. If this information is not available through knowledge of local conditions, air currents may be traced by the use of balloons to determine whether certain winds will, or will not, bring the stack discharge down. The fumes issuing from an incinerator chimney, even if the plant is operating efficiently, will be noticeable and, while perhaps not injurious to health, are undesirable under the above down draft conditions.

The disposal of ashes in parks should not be difficult as 50 to 60 cubic yards of refuse produce only one small truck load of ashes which can be used for fill purposes where needed. Ashes should be handled in such a way as to prevent their becoming air borne and producing air pollution nuisances.

3. Unloading Methods

The unloading facilities needed at the plant will depend on the type of vehicles employed and whether or not the refuse is to be stored or dumped directly into the incinerator.

In parks where bears are prevalent, the refuse should be charged as soon as possible and the area fenced to minimize attraction. A fence also facilitates maintenance by trapping papers, etc. blown by the wind.

Loading platforms should be large enough to facilitate charging of material, necessary storage and, perhaps the can washing facilities as shown on the incinerator layout diagram. Where the refuse cans are transported on trucks, the loading platform should be constructed to be at the same level as the truck bed. If this area is elevated, a guard rail should be provided. An efficiently operating incinerator requires quick unloading of trucks so that delivery time and costs can be kept to a minimum.

4. Charging Methods

Refuse trucks can be unloaded directly onto a charging floor. When this is done, mounds of refuse are heaped in open storage in order to supply the furnaces continuously and to minimize the waiting and unloading time for the trucks. Many incinerators have wing walls, barricades, and charging doors for the introduction of refuse into the primary furnace chamber. Minimum unloading expense is obtained by having the refuse truck unload directly at such wing gate inlets, so that little labor is required to introduce the refuse material. Similarly, it is possible to employ small hoppers directly above the inlet of the furnace into which the refuse truck may unload. Direct charging is common in plants which operate for only 8 to 12 hours per day, and thus, would be most adaptable for NPS use. The collected material is burned immediately with the exception of small quantities of refuse temporarily left in open storage. Hand charging, due to labor costs, is generally the most expensive of all methods.

Another method of handling refuse involves the discharge of segregated or semi-segregated material onto a sorting floor for the salvage of materials. Salvage is governed mainly by the local market for salvage material, and because of location, is generally not feasible at NPS incinerator sites.

In large plants, it is necessary to have storage bins with enough capacity to allow continuous plant operation around the clock. Bin design criteria generally requires a 16 to 24 hour reserve of refuse to be burned. The bins should have pitched floors and drains to facilitate cleaning. In units with large storage bins, traveling bridge cranes or monorails are used for charging the primary furnace. However, it is felt that this would not be applicable to NPS areas.

5. Charging Doors.

Refuse is introduced into the primary chamber of an incinerator through a charging door. This opening can be either on the side of the furnace or on top. Most plants which have been constructed recently have employed top charging because of operating practicalities. Air pollution control authorities, however, advocate side charging because it tends toward more uniform feeding, which enhances optimum combustion. The convenience of top charging is a desirable feature applicable to most NPS installations. Side charging should be seriously considered where air pollution aspects are critical. In either case, it is necessary that overloading be prevented to avoid incomplete combustion.

The dimensions of the charging doors vary. Normally they are about two feet square or two feet in diameter. They are fixed by considering overfire-air requirements, the charging method employed, and/or the type of refuse burned. The charging doors are usually opened only when the refuse is being introduced. However, they may be left open to provide an additional source of overfire-air to meet the demands of wet material. Door stops should be provided for this purpose. In a plant where there is to be a minimum of hand feeding, and a mechanical conveyor or a bulldozer is used to introduce the charge, larger openings are desirable. As for the type of refuse burned, large boxes or other bulky refuse should not govern the size of charging doors, unless a great amount of this type of refuse makes it more efficient to introduce this material without first breaking it up. The main consideration, however, should be ease in opening the doors and controlling excess air. The charging doors are generally lined with firebrick to enable them to withstand the high temperatures generated in the primary chamber. Counter weighted guillotine-type doors are useful on units that are charged from the side.

Stoking doors are used on furnaces even when top charging is employed. These inlets are used for stoking, introducing dead animals, controlling the amount of air, and for observing furnace operation. These side openings are generally covered with hinged doors. Stoking doors and cleanout doors should be provided with adjustable air ports for additional control of excess air. On larger units, counterweighted guillotine-type stoking doors are often used. Whatever the furnace opening, plant operators should be instructed to stand to one side when working as there is always the possibility of a dangerous explosion within the furnace. Compressed gas cylinders commonly used in camp stoves and lanterns are especially dangerous and should be sorted from the refuse before the refuse is charged into the furnace.

6. Size Estimation

The size of an incinerator is governed by the amount of refuse to be consumed on a pound per day basis. It is very important that this calculation be made as accurately as possible. Direct quantitative measurements yield the best data. However, if direct measurement is not possible, the following method should be used:

By means of the field study conducted in 1954 (Bibliography Reference No. 9), basic park refuse quantity data are obtained. These are summarized in section 7 of this part of the manual, and is used here to convert from contributing population to pounds of refuse per day. The conversion factors vary considerably among the different park facilities and the type of refuse to be burned.

A study must be made of the area from which the refuse is to be collected to determine the contributing population. It is suggested that design be made on an average peak load basis; that is, by averaging the maximum daily number of people at the site during each week of the busy season. Growth should not be overlooked. Therefore, it is advisable to consider the average peak load over a period of at least ten years hence. Extreme peak loads contributed by holiday crowds, should not be used in the data as excessive loads may be incinerated by providing for overtime use of the plant. Park incinerators should be designed to consume the expected refuse during one 8-hour shift per day. The actual charging time would be about five hours, allowing time for proper heating up, cooling and cleaning. Automatic controls may be installed as optional equipment for the purpose of heating up the incinerator before the first load arrives in the morning, and thus, increasing the charging time by one to two hours.

7. Basic Refuse Quantity Data

Facility	Types of Waste	Pounds Per Capita Per Day			Cubic Feet Per Capita Per Day			% of Garbage and Rubbish in Refuse	
		Average Minimum	Average Maximum	Median of Average	Average Minimum	Average Maximum	Median of Average	By Weight	By Volume
Lodges & Hotels	Combined Refuse	1.79	3.90	3.5	0.43	0.59	0.43		
	Garbage	1.89	5.04	2.0	0.08	0.13	0.09	60	15
	Rubbish	1.15	3.24	1.3	0.33	0.67	0.37	40	85
Campgrounds	Combined Refuse	0.45	1.60	1.4	0.07	0.41	0.18		
	Garbage	--	--	--	--	--	--	40	20
	Rubbish	--	--	--	--	--	--	60	80
Picnic Areas	Combined Refuse	--	--	0.4	--	--	0.07		
Park Hdqrs. Area (Including residences and Maintenance Areas)	Combined Refuse	1.52	2.82	2.0	0.28	0.51	0.40		
	Garbage	--	--	--	--	--	--	53	20
	Rubbish	--	--	--	--	--	--	47	80

NOTE: Ashes are excluded from the above table; the relative error is small. The figures shown are for facilities which are not necessarily in the same location. Therefore, amounts of garbage plus rubbish do not always equal the amount of combined refuse.

SOURCE: Reference No. 9, Bibliography.

As an example, it is assumed that an area has an average peak load contributing to the incinerator of 620 people staying at lodges and hotels, 200 making use of campgrounds and 25 park headquarters personnel. Referring to the median of average values in pounds per capita per day in the Basic Refuse Quantity Data Table, the design load of the incinerator is found as follows:

620 x 3.5 = 2170 lbs. of refuse from lodges and hotels

200 x 1.4 = 280 lbs. from campgrounds

25 x 2.0 = 50 lbs. from park headquarters

This equals a total of 2,500 lbs. of refuse to be consumed by the incinerator per day. (This figure is used in Part III, Engineering Design.)

In areas which produce less than five tons of refuse per day, (less than 5,000 population), a single-unit plant (one furnace) is best. In such a small installation, no bin, crane, ash hopper, ash tunnel, charging hoppers, charging grates, forced draft fans, or, in fact, any mechanical devices are justified. However, as in the design example in Part III, auxiliary fuel apparatus is a necessity when wet garbage is being burned. If, when the design does not warrant auxiliary fuel apparatus and additional fuel is required on rare occasions when material is water-soaked, then a small amount of soft coal or wood will be the most economical solution. A constant source of auxiliary heat involves fixed charges and maintenance. Auxiliary fuel is used in the incinerator designed in Part III of this manual and will probably be necessary in most park units.

A plant for areas of from 5,000 to 20,000 people might have two furnaces, but will not need a bin and crane, nor an ash tunnel and ash hopper. In the lower brackets, it is highly probable that only one furnace unit should be built.

A plant for 20,000 to 50,000 people may be equipped with either a bin and crane, or a ramp leading directly to the charging floor. A two or three shift operation should be considered in this case. Also, the situation may call for two conveniently located units as the most economical.

8. Furnace Chamber

The furnace chamber of an incinerator should be designed to promote the rapid desiccation of the raw refuse leaving only the volatile gases to be burned in the mixing chamber and ashes to fall into the ash pit.

The grate area in the furnace increases at a decreasing rate with the size of the plant. (See the furnace design section, in Part III for calculations of grate area and arch height). The relationships used take into account usual air pollution control requirements.

The primary furnace chambers are normally lined with a minimum thickness of 9 inches of refractory material and 4 inches of insulation material. The refractories should be of the best quality available, preferably super duty fire brick. They should be constructed in accordance with acceptable refractory construction methods as specified by the refractory manufacturers, well-maintained, and whenever possible, operated at temperatures above 1,000°F. The temperature range, up to 1,000°F. is the critical range where maximum expansion and contraction of the expensive refractory material and resulting deterioration takes place. Refractories should be designed to operate at temperatures up to 2400°F., with the optimum burning temperatures maintained in the neighborhood of 1300°F. to 2000°F. within the primary chambers. It is advisable to install indicating pyrometers in the furnace and secondary combustion chamber for observing temperatures. This results in a minimum of thermal stresses and maximum life, as well as good operating conditions for the primary chamber. The refractories and grates should be installed with future replacement as a consideration.

9. Flame Port

This is the passageway connecting the furnace and the mixing chamber. A gas velocity of from 45 to 65 feet per second should be maintained at this point.

10. Mixing Chamber

The mixing chamber is where the volatile gases mix and burn, thus relieving odor and toxicity. Velocities in this chamber should range between 20 and 30 feet per second. The refractories and insulation should be of the same quality and thickness as in the furnace chamber.

11. Curtain Wall

This is the passageway connecting the mixing chamber and the secondary combustion chamber. Velocities between 15 and 25 feet per second are desirable here.

12. Secondary Combustion Chamber

In this chamber, also called the expansion chamber, combustion gases expand, burn out, and fly ash settles. Velocities in this chamber should be about 5 to 6 feet per second, and again, high quality refractories should be used. The volume of this chamber should be based on 10 to 12 cubic feet per ton of rated daily (24 hour) capacity, or the velocity, whichever is greater. Fly ash is cleaned from this chamber and the mixing chamber when the plant is shut down for routine cleaning.

In large plants, the use of baffles in the expansion chamber improves the mixing of the gases and increases impingement of the fly ash.

Many small plants combine the mixing chamber and the secondary combustion chamber into one.

13. Flues

A flue is the connection between the secondary combustion chamber and the chimney. In large plants, when more than one furnace is employed, the flues are inter-connected so that one chimney can serve two or more units. Since some fly ash is deposited in the flues, they should be readily accessible for cleaning. Curb walls, which function like snow fences, are sometimes used in flues to further stop fly ash from reaching the chimney. The cross-sectional area of a flue usually ranges from 1/4 to 1 square foot per ton of daily rated capacity. For park incinerators, 1/2 square foot per ton of daily rated capacity is recommended in the design of flues. Walls should be so constructed as to be well insulated and both heat and gas tight.

14. Dampers

Dampers are used to control furnace draft and to cut off draft when the incinerator is closed down. A convenient location for the damper is in the flue just before the chimney as shown on the incinerator diagram in Part III. Dampers, being located in a relatively hot part of the incinerator, should be made of steel. (Supported refractory is used on many larger units). Dampers are counter-weighted for easy operation.

15. Chimneys

Chimney dimensions are important to obtain proper draft for the incinerator and disperse the gases over a wide area in a nuisance-free manner. They should be tall enough to clear the highest obstacle. Steel chimneys are recommended for small incinerators such as those used in the national parks. See part III for the formula used in the design of the chimney.

16. Can Washing

An important appurtenance to the incinerator is a device for the washing of cans and trucks. A heat exchange unit to supply hot water may be installed for washing purposes with an outlet located near the charging inlet, so that equipment can conveniently be washed after the refuse is dumped. The heating coils should be located within the incinerator to take advantage of the heat from one of the auxiliary fuel burners, if any are provided. This would be a more reliable heat source for can washing purposes since another chamber may not supply enough heat during the period when little refuse is being burned. Calculations must be made for the sizing and location of the coils. Flow should not be continuous, but may be started by a foot-operated, self-closing stop which is conveniently located. A hose connection for truck washing and for flushing the area may use this same hot water source. A water supply source and storage provision may need to be developed for this purpose. A backflow prevention device is necessary if a potable water source is used. Some park incinerator sites have made successful use of portable, instantaneous steam generators (steam jennies) for can washing.

17. Drainage

Another provision that should be planned is the drainage at the incinerator by either a separate system, or by connecting into an existing sewerage system. Septic tanks and sub-surface tile lines have been provided at some incinerators for waste disposal from can washing operations. As shown on the "Layout of Incinerator" diagram, the charging platform should drain away from the charging inlet and toward the drain located near the can washing area. Drainage should also be away from the edge of the platform to keep the roadway as dry as possible.

PART III

ENGINEERING DESIGN

The design factors for either a small or large plant are essentially the same, as the burning process in both cases is the same. Small units may not justify expensive refuse handling equipment, but the engineering design and operating criteria are similar.

As an example, an incinerator will be designed to burn the refuse from the area assumed in Size Estimation, Part II. The composition of the refuse which is to be incinerated must first be determined. It is assumed that a field investigation shows that the refuse approximates the average composition for lodges and hotels. From the table of Basic Refuse Quantity Data, the refuse is made up of 60% garbage and 40% rubbish. Furthermore, it is found that an average 100 lb. sample is composed of the following:

		45 lb. water
Garbage:	60%	15 lb. combustible material
		8 lb. water
Rubbish:	40%	24 lb. combustible material
		8 lb. inert material
		53 lb. water
Or a Total of:	100%	39 lb. combustible material
		8 lb. inert material

On the basis of the above, the refuse is composed of 53% water, 39% combustible, and 8% inert material.

The combustible component of refuse for design purposes may be considered the same as cellulose ($C_6 H_{10} O_5$) and has a heating value of 8,000 BTU/lb. on a dry basis. Actually, average refuse contains a small percentage of carbohydrates ($C_5H_{10}O_5$) and fats ($C_{20} H_{30} O_2$), but these do not influence the design significantly. Therefore, for ease in computation, cellulose alone will be considered.

THERMODYNAMIC CONSIDERATIONS

A heat balance must be made. This is a comparison of heat required to the heat available at the desired temperature in order to determine the amount of excess air, and, if necessary, the auxiliary fuel to properly consume the combustible refuse and to evaporate the water present.

The basic combustion formula and the molecular weights of the substances in the reaction are as follows:

	$C_6H_{10}O_5$	+ 60_2	→ $6CO_2$	+ $5H_2O$
Mol. Combining Weights*	162	192	264	90
Lb./lb. refuse	0.39	0.46	0.64	0.22

The number of lbs. of each substance per lb. of refuse is found by direct proportion of the molecular weights of each substance, knowing first that the combustible material is 39% of each pound of refuse. Thus, the 60_2 weighs 0.39 x 192 ÷ 162 = 0.46 lb./lb. of refuse.

The oxygen required = 0.46 lb./lb. of refuse.

Air = 23% by weight.

Air required = $\frac{0.46}{0.23}$ = 2.00 lb./lb. of refuse.

The amount of excess air (usually between 100 and 200%) must be assumed at this point.

Assume 150% excess air.

∴ Air used = 2.5 x 2.00 = 5.00 lb./lb. of refuse.

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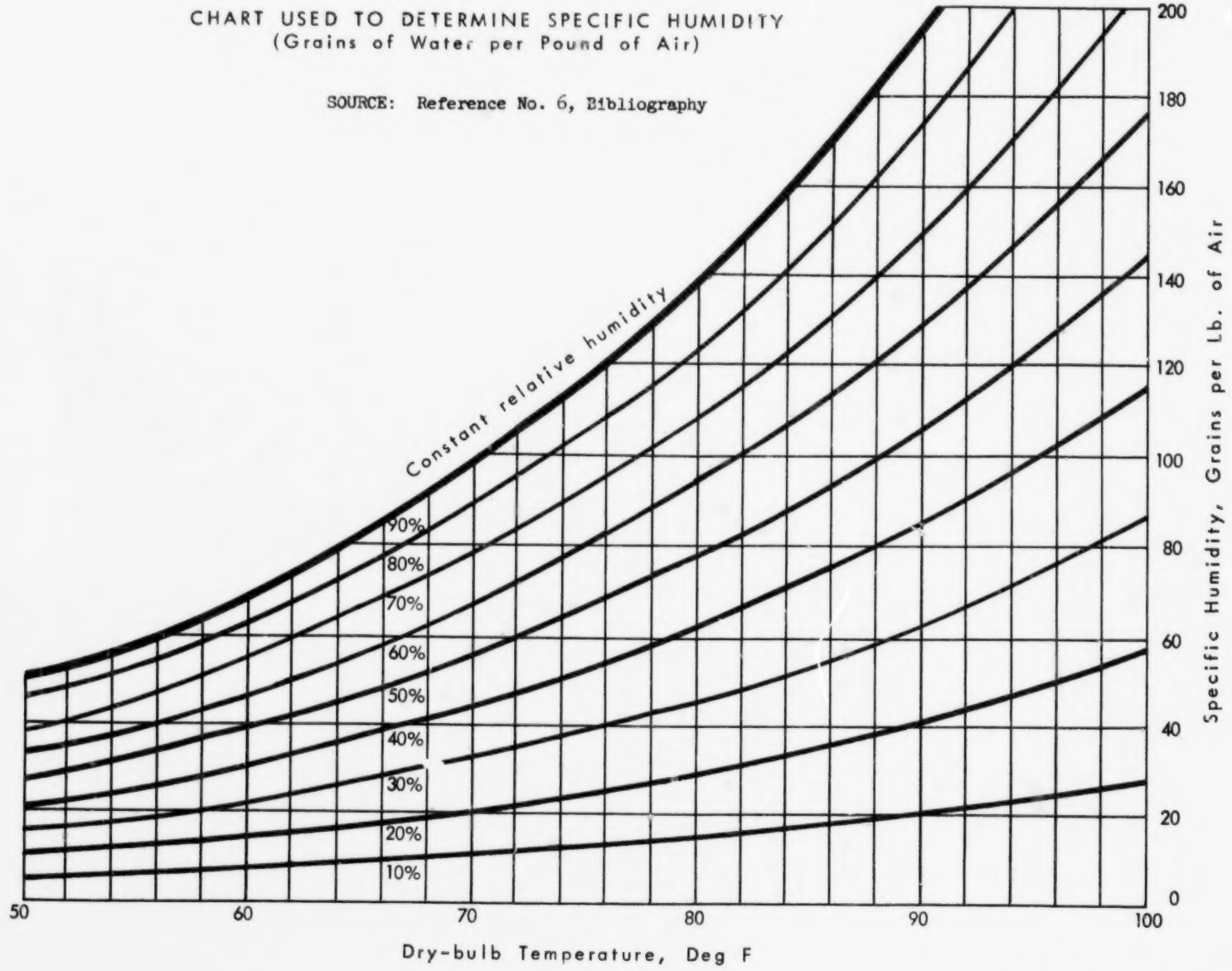
* NOTE: Atomic weights are: C = 12, H = 1, and O = 16.

CHART USED TO DETERMINE SPECIFIC HUMIDITY
(Grains of Water per Pound of Air)

SOURCE: Reference No. 6, Bibliography



Calculations for total water in stack gas:

The average relative humidity which would have to be determined locally is assumed to average 65% at 60°F. at this hypothetical geographical area, thus using 51 grains of water in 1 lb. of dry air. (See Table, Page 15).

$$\text{Total moisture in air used} = \frac{51 \text{ gr.}}{1 \text{ lb. air}} \times \frac{1 \text{ lb. water}}{7{,}000 \text{ gr.}} \times \frac{5.00 \text{ lb. air}}{1 \text{ lb. refuse}}$$

$$= 0.04 \text{ lb. water/lb. refuse.}$$

Summation of H_2O in stack gas:

Moisture of refuse	0.53 lb./lb. refuse
Water in air used	0.04 "
Water formed during combustion	0.22 "
Total Water in Stack Gases	0.79 lb./lb. refuse

Heat Requirements:

(a) To raise the temperature of H_2O from 60°F. to 212°F. (1 BTU is required to raise the temperature of 1 lb. of H_2O 1°F.)

= 0.79 lb. H_2O/lb. refuse x (212°F. - 60°F.) x 1.0 BTU/lb. H_2O/°F.

= 120 BTU/lb. refuse

(b) To evaporate H_2O.
(Latent heat of evaporation = 970.3 BTU/lb. H_2O.)

= 0.79 lb. H_2O/lb. refuse x 970.3 BTU H_2O

= 766 BTU/lb. refuse

(c) To raise steam to 1300°F.
(Specific heat of steam = 0.5 BTU/lb. H_2O/°F.)

= 0.79 lb. H_2O/lb. refuse x (1300°F. - 212°F.) x 0.5 BTU/lb. H_2O/°F.

= 430 BTU/lb. refuse

(d) Heat required to raise stack gases due to combustion to 1300°F. (Specific heat of gases approximates 0.26 BTU/lb. gas).

Total weight of combustion gases
= 5.00 lb. air - 0.46 lb. O_2 + 0.64 lb. CO_2
= 5.18 lb. gas/lb. refuse.

= 5.18 lb. gas/lb. refuse x (1300°F. - 60°F.) x 0.26 BTU/lb. gas
= 1670 BTU/lb. refuse.

(e) Heat loss through inert material (residue). (Specific heat of inert material assumed as 0.2 BTU/lb. inert/°F.) Temperature of inert material (8% of total refuse) is assumed to be 500°F.

= 0.08 lb. inert/lb. refuse x (500°F. - 60°F.) x 0.2 BTU/lb. inert/°F.

= 7 BTU/lb. refuse

(f) Heat loss through furnace doors, refractories, etc., assumed to be 20% of heat available.

Heat available/lb. refuse
= % combustible x $\frac{\text{heat value - BTU}}{\text{lb. dry refuse}}$

= 0.39 x 8000 BTU/lb. refuse

= 3120 BTU/lb. refuse

Heat loss = 0.20 x 3120 = 624 BTU/lb. refuse.

Summation of heat balance (BTU/lb. refuse):

Heat Required			Heat Available	
For Moisture in combustion (a + b + c)	=	1316	From combustible material	3120
For gases in combustion (d)	=	1670		
Loss through residue (e)	=	7		
Loss through furnace (f)	=	624		
TOTALS		3617 BTU/lb. refuse		3120 BTU/lb. refuse

Auxiliary heat required = 3617 - 3120 = 497 BTU/lb. refuse.

Since the heat available is appreciably less than the heat required, a constant supply of auxiliary fuel is necessary. Calculations using oil as the auxiliary fuel follow.

Had the heat available approximated the heat required (within 1%) or exceeded the heat required, auxiliary fuel would not be needed. The availability of excess heat would mean that: (1) The furnace temperature would exceed 1300°F., or (2) More air would be required to maintain the 1300°F. temperature. This is a desirable condition since furnace temperatures between 1300°F. and 1800°F. are acceptable for satisfactory operation.

CALCULATIONS USING OIL AS THE AUXILIARY FUEL

The recommended oil is P. S. (Pacific Standard) #100, which is kerosene or distillate. It should be burned with 30% excess air. Physical properties of P. S. #100 are as follows (from oil properties table, page 19):

(1) Approximate heat value - 19,910 BTU/lb. oil.

(2) The volume and weight of flue gas at 60°F. created by 1 lb. of oil at 30% excess air = 270.90 cubic feet and 20.49 lbs. This is composed of 30.13 cubic feet (1.43 lb.) of water and 240.77 cubic feet (19.06 lbs.) of dry flue gas.

(3) Pounds of oil per gallon = 6.83 lb./gal.

Heat Requirements:

(a) To raise the temperature of H_2O from 60°F. to 212°F.

= 1.43 lb. H_2O/lb. oil x (212°F. - 60°F.) x 1.0 BTU/lb. H_2O/°F.

= 218 BTU/lb. oil

(b) To evaporate H_2O.

= 1.43 lb. H_2O/lb. oil x 970.3 BTU/lb. H_2O

= 1388 BTU/lb. oil

PHYSICAL PROPERTIES AND COMBUSTION DATA FOR FUEL OILS

PACIFIC STANDARD NUMBER		P. S. #100		P. S. #200	P. S. #300	P. S. #400
	GRADE	#1	#2	#3	#5	#6
	Common Name	Kerosene Distillate		Straight Run Fuel Oil	Low Crack Fuel Oil	Heavy Crack Fuel Oil
Typical Analysis	Carbon C	84.7 %		85.8 %	87.5 %	88.3 %
	Hydrogen H	15.3 %		12.1 %	10.2 %	9.5 %
	Sulphur S	.02 %		1.2 %	1.1 %	1.2 %
	Water H_2O	--		--	.05%	.05%
	Other	--		0.9 %	1.1 %	1.0 %
	Lbs. /Gallon	6.83		7.50	8.00	8.33
	Sp. Gr. 60°/60°	0.82		0.90	0.96	1.00
	Approximate BTU/Gallon	136,000		142,000	146,000	152,000
	Approximate BTU/#	19,910		18,950	18,250	18,000
Specifications		#1	#2			
	Max. Viscosity	--	--	45 sec. 100°F. **	40 sec. 122°F. ***	300 sec. 122°F. ***
	Flash Point Minimum	110°F.	125°F.	150°F.	150°F.	150°F.
	Flash Point Maximum	165°F. *	190°F. *	200°F. *	--	--
	Max. Water and Sediment	0.05%	0.05%	0.1%	1.0%	2.0%
	Max. 10% Point	420°F.	440°F.	460°F.	--	--
	Max. 90% Point	--	620°F.	675°F.	--	--
	Max. End Point	600°F.	--	--	--	--

* Or Legal Maximum ** Saybolt Universal *** Saybolt Furol

COMBUSTION DATA

BASIS: 1# FUEL OIL

(Combustion products calculated for combustion with air 40% saturated at 60°F.
All volumes measured as gases @ 60°F. Moisture in fuel included where indicated.)

Constituent		P. S. #100		P. S. #200		P. S. #300		P. S. #400	
		Cubic Feet	Pounds	Cubic Feet	Pounds	Cubic Feet	Pounds	Cubic Feet	Pounds
Theoretical Air (40% Saturated @ 60°F.)		197.3	15.04	185.1	14.11	179.1	13.66	177.2	13.51
Flue Gas Constituents With Theoretical Air	CO_2	26.73	3.104	27.08	3.144	27.61	3.207	27.86	3.236
	SO_2	.002	.0004	.142	.0240	.130	.0220	.142	.0240
	N_2	154.8	11.44	145.2	10.74	140.5	10.39	139.0	10.28
	H_2O formed	28.76	1.368	22.75	1.082	19.18	.9118	17.86	.8491
	H_2O (fuel)	--	--	--	--	.011	.0005	.011	.0005
	H_2O (air)	1.367	.0662	1.283	.0621	1.242	.0601	1.228	.0595
	TOTAL	211.659	15.9786	196.455	15.0521	188.673	14.5914	186.101	14.4491
Amount of Flue Gas With Percentage Excess Air As Indicated	0 %	211.7	15.98	196.5	15.05	188.7	14.59	186.1	14.45
	7.5%	226.5	17.11	210.4	16.11	202.1	15.62	199.4	15.46
	10.0%	231.4	17.48	215.0	16.46	206.6	15.96	203.8	15.80
	12.5%	236.4	17.86	219.6	16.81	211.1	16.30	208.3	16.14
	15.0%	241.3	18.24	224.3	17.17	215.6	16.64	212.7	16.48
	17.5%	246.2	18.61	228.9	17.52	220.0	16.98	217.1	16.81
	20.0%	251.2	18.99	233.5	17.87	224.5	17.32	221.5	17.15
	30.0%	270.9	20.49	252.0	19.28	242.4	18.69	239.3	18.50
	40.0%	290.6	22.00	270.5	20.69	260.3	20.05	257.0	19.85
	50.0%	310.4	23.50	289.1	22.11	278.3	21.42	274.7	21.21
	75.0%	359.7	27.26	335.3	25.63	323.0	24.84	319.0	24.58
	100.0%	409.0	31.02	381.6	29.16	367.8	28.25	363.3	27.96

(c) To raise steam to 1300°F.

= 1.43 lb. H_2O/lb. oil x (1300°F. - 212°F.) x 0.5 BTU/lb. H_2O/°F.

= 777 BTU/lb. oil

(d) Heat required to raise flue gas due to combustion of oil to 1300°F.

= 19.06 lb. gas/lb. oil x (1300°F. - 60°F.) x 0.26 BTU/lb. gas/°F.

= 6145 BTU/lb. oil

Heat available per lb. of oil at 1300°F. and 30% excess air.

= 19,910 - (a + b + c + d)
= 19,910 - (218 + 1,388 + 777 + 6,145)

= 19,910 - 8,528 = 11,382 BTU/lb. oil

Auxiliary Heat Required = 497 BTU/lb. refuse.

Pounds of oil required per pound of refuse burned.

$$= \frac{497 \text{ BTU/lb. refuse}}{11,382 \text{ BTU/lb. oil}} = 0.0437 \text{ lb. oil/lb. refuse}$$

Volume of flue gas due to auxiliary fuel.

= 270.90 cu. ft./lb. oil x 0.0437 lb. oil/lb. refuse.

= 11.8 cu. ft./lb. refuse.

ESTIMATE OF GAS VOLUME

The volume of gas produced in the refuse combustion process is an important factor in determining chamber sizes. All of the "products of combustion" must be accounted for, including the nitrogen and excess air, even though they do not react during the combustion process.

The volume of the "products of combustion" is determined as follows: The basic combustion equation is: $C_6H_{10}O_5 + 6O_2 \rightarrow 6CO_2 + 5H_2O$.

The 6 mols of O_2 are present as a part of the air. On the volume basis, air contains 21% oxygen and 79% atmospheric nitrogen. Therefore, in order to take nitrogen (a "product of combustion") into account,

The number of mols of N_2 accompanying the O_2 is $6 \frac{(79)}{(21)} = 22.6$ mols.

The equation now becomes:

$$C_6H_{10}O_5 + 6O_2 + 22.6N_2 \longrightarrow 6CO_2 + 5H_2O + 22.6N_2.$$

The volume of excess air must now be included. As assumed in the heat balance, 150% excess air will be used. One mol of cellulose requires, theoretically, 6 mols of oxygen. The excess oxygen, with 150% excess air equals (1.5) (6) = 9 mols, and the total oxygen to be supplied = 6 + 9 or 15 mols.

The total nitrogen = $15 \times \frac{(79)}{(21)} = 56.4$ mols.

The final combustion equation becomes:

$$C_6H_{10}O_5 + 15O_2 + 56.4N_2 \longrightarrow 6CO_2 + 5H_2O + 56.4N_2 + 9O_2.$$

NOTE: The excess O_2 appears as O_2 on the right hand side of the equation, and the total N_2 appears on both sides.

The total number of mols of "products of combustion" per mol of combustible refuse = 6 + 5 + 56.4 + 9 = 76.4. The atomic weight of C = 12, H = 1, and O = 16; therefore, a mol of combustible refuse ($C_6H_{10}O_5$) weighs (6) (12) + 10 + (5) (16) = 162 lbs. Hence, a pound of combustible refuse equals 1/162 = 0.00617 mols.

The volume of gas at 1300°F. and atmospheric pressure is calculated as follows:

$PV = MRT$, Where:

P = Pressure, pounds per square foot absolute.

V = Volume, cubic feet.

M = The number of mols.

R = Universal gas constant, 1545 $\frac{\text{ft. lb.}}{(\text{mol})(^{\circ}\text{R})}$

T = Temperature, degrees Rankine (°F. + 460)

$$V = \frac{MRT}{P}$$

$$= \frac{0.00617\ (76.4)\ (1545)\ (1300 + 460)}{144\ \ (14.7)}$$

= 605 cu. ft. per lb. of refuse.

To this must be added the volume of flue gas due to the auxiliary fuel, which is 11.8 cu. ft./lb. refuse.

The total gas volume = 605 + 11.8 = 616.8 cu. ft. per lb. of refuse at assumed temperature conditions.

FURNACE DESIGN

The loading conditions must be established. It is assumed that a study concludes that the average peak load from this lodge and hotel is 2, 500 lb. of refuse per day, as determined in Size Estimation, Part II. The burning cycle for an 8-hour shift will be five hours. This allows three hours for heating up, cooling down, and cleaning out properly. This also allows for the extension of the cycle to a two or three shift basis if there is future expansion in the area.

The following grate loading equation and arch height graph take air pollution factors into account, and are the best available at this time. (Reference No. 7, Bibliography).

The grate loading is computed as follows:

$$G_l = 16.5 \nearrow 9 \text{ Log } C_r.$$

Where G_l = grate loading, lb. per sq. ft. of grate area per hour,

C_r = burning rate, lb. per min.

$$= \frac{2500}{5 \times 60} = 8.33 \text{ lb./min.}$$

$$G_l = 16.5 \nearrow 9 \text{ Log } 8.33$$

$$= 16.5 \nearrow 9 (0.921) = 16.5 \nearrow 8.3$$

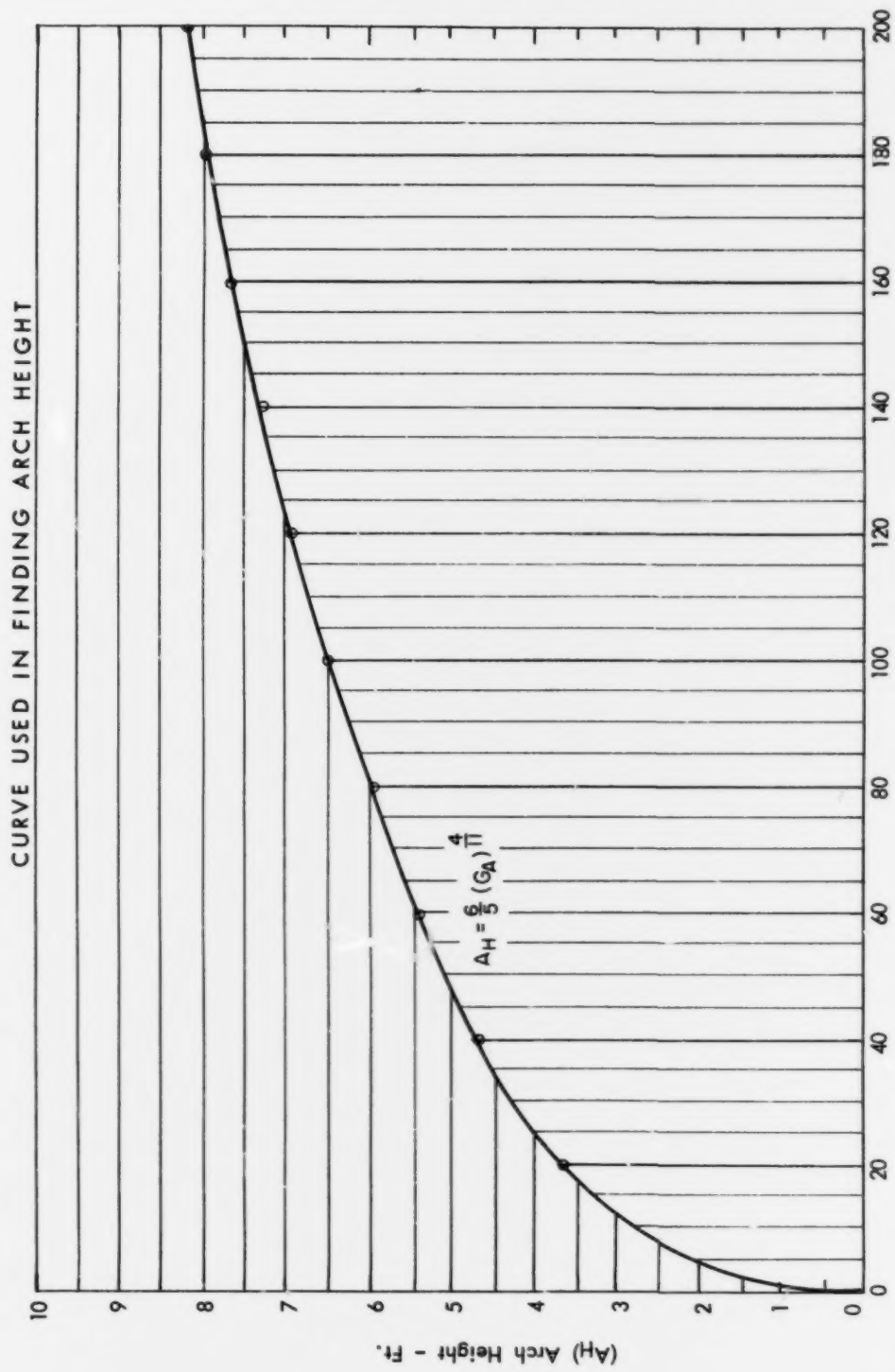
$$= 24.8 \text{ lb./sq. ft./hr.}$$

$$\text{Grate area} = \frac{\frac{2500 \text{ lb./hr.}}{5}}{24.8 \text{ lb./sq. ft./hr.}} = 20.2 \text{ sq. ft.}$$

Arch Height (See graph, page 24) = 3.6 ft.
Use 3' - 7".

Furnace Proportions-- Length = 5' - 5"
Width = 3' - 9" } = 20.3 sq. ft. (W = 0.7 L)
Height = 3' - 7"

Allow 2' - 0" under furnace grate for ash pit. For grates, use 3/8 x 3" steel bars upright and spaced at 4" c. to c.



SOURCE: Reference No. 7, Bibliography

FLAME PORT DESIGN

The gas volume at 1300°F. = 616.8 cu. ft./lb.

Velocity of gases = 55.0 ft./sec.

Gas flow (Q) at 1300°F.
= 616.8 cu. ft./lb. x 8.33 lb./min. x $\frac{1 \text{ min.}}{60 \text{ sec.}}$ = 85.6 cu. ft./sec.

$$Q = AV$$

$$A = \frac{Q}{V} = \frac{85.6}{55.0} = 1.56 \text{ sq. ft.}$$

Use Width equal to Furnace Width = 3' - 9".

Depth = $\frac{1.56}{3.75}$ = 0.42 ft. Use 0' - 5".

For the purpose of adjusting the gas flow, the six inch layer of fire brick under the flame port should be held by gravity only for ease in movement (See incinerator diagram, page 32.)

MIXING CHAMBER DESIGN

Gas flow (Q) at 1300°F. = 85.6 cu. ft./sec.

Velocity of gases = 25.0 sq. ft./sec.

$$A = \frac{Q}{V} = \frac{85.6}{25.0} = 3.43 \text{ sq. ft.}$$

Use Width equal to Furnace Width = 3' - 9".

Depth = $\frac{3.43}{3.75}$ = 0.92 ft. Use 1' - 0".

The length is governed by the furnace size, and since this chamber goes down the side of the furnace, it will equal the height of the furnace or 3' - 7" / 2' - 0" = 5' - 7".

Mixing chamber proportions -- Width = 3' - 9"
Depth = 1' - 0"

CURTAIN WALL DESIGN

Gas flow (Q) at 1300°F. = 85.6 cu. ft./sec.

Velocity of gases = 20.0 ft./sec.

$A = \frac{85.6}{20.0} = 4.28$ sq. ft.

Use Width equal to Furnace Width = 3' - 9"

Depth = $\frac{4.28}{3.75}$ = 1.14 ft. Use 1' - 2".

SECONDARY COMBUSTION CHAMBER DESIGN

Gas flow (Q) at 1300°F. = 85.6 cu. ft./sec.

Velocity of gases = 6.0 ft./sec.

$A = \frac{Q}{V} = \frac{85.6}{6.0} = 14.30$ sq. ft.

Use Width equal to Furnace Width = 3' - 9"

Depth = $\frac{14.30}{3.75}$ = 3.82 ft. Use 3' - 10"

As in the case of the mixing chamber, the length of the secondary combustion chamber = 5' - 7". The volume of this chamber using the velocity design basis is 3.75 x 3.83 x 5.58 = 80 cu. ft.

Design on the volume basis must now be considered, based on 11 cu. ft. per ton of rated daily capacity.
The rated daily capacity = $\frac{500 \text{ lb./hr.} \times 24 \text{ hr./day}}{2000 \text{ lb./ton}}$ = 6 tons/day.

The volume = 11 cu. ft./ton/day x 6 tons/day = 66 cu. ft.
This is less than the volume using the velocity basis for design. Therefore, the velocity design should be used.

Secondary combustion chamber proportions--

Width = 3' - 9"

Depth = 3' - 10".

SECONDARY AIR PORTS

At a velocity head of 0.025 in. of H_2O, the velocity at the secondary air inlet = 10 ft./sec. = 600 ft./min.

The volume of secondary air should be 50% of the theoretical air requirements at standard conditions of temperature and pressure. Theoretical air is the air necessary for the combustion of the refuse, excluding the excess air. Referring to the section "estimate of gas volume", the formula used for theoretical air is:

$$C_6H_{10}O_5 + 6O_2 + 22.6N_2 \longrightarrow 6CO_2 + 5H_2O + 22.6N_2$$

The weight of one pound of combustible refuse remains at 0.00617 mols. The total number of mols of theoretical air per mol of combustible refuse becomes: 6 + 22.6 = 28.6.

The volume of air at 60°F. and 14.7 psi is calculated as follows:

$$V = \frac{MRT}{P} = \frac{0.00617\ (28.6)\ (1545)\ (60 + 460)}{144\ (14.7)} = 67.0 \text{ cu. ft./lb. of refuse}$$

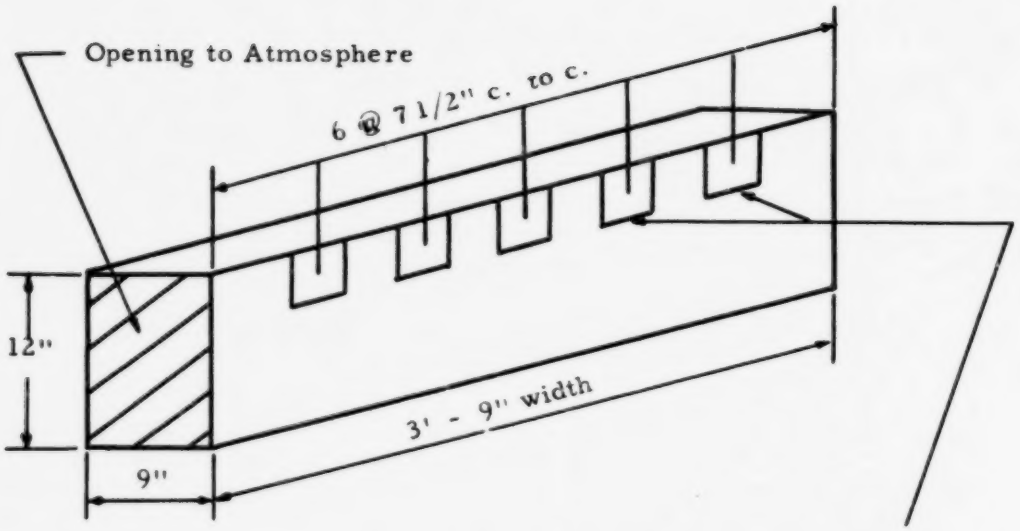
Air Flow = 0.50 x 67.0 cu. ft./lb. refuse x 8.33 lb. refuse/min.
= 280 cu. ft./min.

$$\text{Air Flow Area Required} = \frac{280 \text{ cu. ft./min.}}{600 \text{ ft./min.}} = 0.47 \text{ sq. ft.}$$

Five openings to the mixing chamber @ 4" x 4" yield 0.555 sq. ft.

The openings to the atmosphere should be at least 2/3 the air flow area = 2/3 x 0.555 = 0.37 sq. ft. The opening at each end of the duct should be 0.37 sq. ft. Since, in this design, only one end is open to the atmosphere, the area of this opening must be doubled (= 0.74 sq. ft.).

Use opening 9" x 12" = 0.75 sq. ft.



5 Openings from Duct
to Mixing Chamber,
each 4" x 4".

AUXILIARY FUEL BURNERS

Using P. S. #100 oil as auxiliary fuel, it was previously calculated that 0.0437 lb. oil/lb. refuse burned is required. Oil burners are usually rated in gallons of oil supplied per hour. There are 6.83 lbs. of oil per gallon of P. S. #100 oil.

$$\text{Rating per burner} = 0.0437 \text{ lb. oil/lb. refuse} \times \frac{500 \text{ lb. refuse}}{\text{hr.}} \quad \frac{1 \text{ gal. oil}}{683 \text{ lb. oil}}$$

$$= 3.2 \text{ gal. oil/hr.}$$

It is recommended that continuous ignition type burners be installed to meet this need. As shown on the incinerator diagram, one burner supplies heat to the piled-up refuse in the furnace, and the other to the gases as they enter the mixing chamber. It is probable that the burners will not need to be in constant operation. They will be needed during initial ignition and when wet loads of refuse are introduced into the furnace.

FLUE DESIGN

This incinerator will have a flue area computed on a basis of 1/2 sq. ft. per ton of rated daily capacity.

$$\text{The rated daily capacity} = \frac{500 \text{ lb./hr.} \times 24 \text{ hr./day}}{2000 \text{ lb./ton}}$$

$$= 6 \text{ tons/day}$$

Flue area = 1/2 x 6 = 3 sq. ft.

Use dimensions = 1' - 6" wide x 2' - 0" deep

The length is determined by the fact that the stack damper is located in the flue. (See incinerator diagram). Use a flue length of 2' - 0".

DAMPER DESIGN

A 1/4" steel damper should be used. A 1' - 6" x 2' - 6" piece can be cut down to fit into steel runners located in the flue, and in such a position to be opened and closed easily. The chimney can be used as a pulley point for the counter-weighted damper.

CHIMNEY DESIGN

The chimney temperature should be approximately 750°F., and the draft loss approximately 1/4" of water.

The following formula (Bibliography Reference No. 6) is used to obtain the proper chimney dimensions for the necessary draft:

$$d = KH - \frac{(fW^2CH)}{A^3}, \text{ where:}$$

d = Draft loss, in. of water (= 1/4" H_2O)

K = Temperature Constant (= 0.0084 for 750°F.)

H = Chimney height, Ft.

f = Constant for chimney material (= 0.00175 for steel stack at 750°F.

W = Weight of gases passing per sec., lb./sec.

C = Circumference of stack, feet.

A = Area of stack, sq. ft.

Constants for other stack conditions can be found in most mechanical engineer's handbooks.

The weight of gases passing per sec., W, must be computed. The gas volume of 616.8 cu. ft. per lb. of refuse is for 1300°F., and must be converted to 750°F. This new volume becomes:

$$616.8 \frac{(750 + 460)}{(1300 + 460)} \cdot \frac{424 \text{ cu. ft. gas @ } 750^{\circ}\text{F.}}{\text{lb. refuse}}$$

At this point, the gases can be assumed to be air which has a mol. wt. of 29. The molal volume of any gas at standard conditions (32°F. and 14.7 psi) = 359 cu. ft./lb. mol. Converting to 750°F., the molal volume becomes:

$$359 \frac{(750 + 460)}{(32 + 460)} = 882 \text{ cu. ft./lb. mol.}$$

The total weight of the gases due to the 8.33 lb. of refuse burned per min. equals:

$$W = \frac{\frac{8.33 \text{ lb. refuse}}{\text{min.}} \times \frac{424 \text{ cu. ft.}}{\text{lb. refuse}} \times \frac{29}{\text{mol.}}}{60 \text{ sec./min.} \times 882 \text{ cu. ft./lb. refuse}} = 1.93 \text{ lb./sec.}$$

Let us assume a circular stack of 2' - 0" inside diameter.

$$A = \frac{\pi D^2}{4} = \frac{\pi (2.0)^2}{4} = 3.14 \text{ sq. ft.}$$

$$C = \pi D = \pi (2.0) = 6.28 \text{ ft.}$$

We may now solve for the chimney height:

$$d = KH - \frac{(f\ W^2\ CH)}{A^3}$$

$$0.25 = 0.0084\ H - \frac{0.00175\ (1.93)^2\ (6.28)}{(3.14)^3}\ H$$

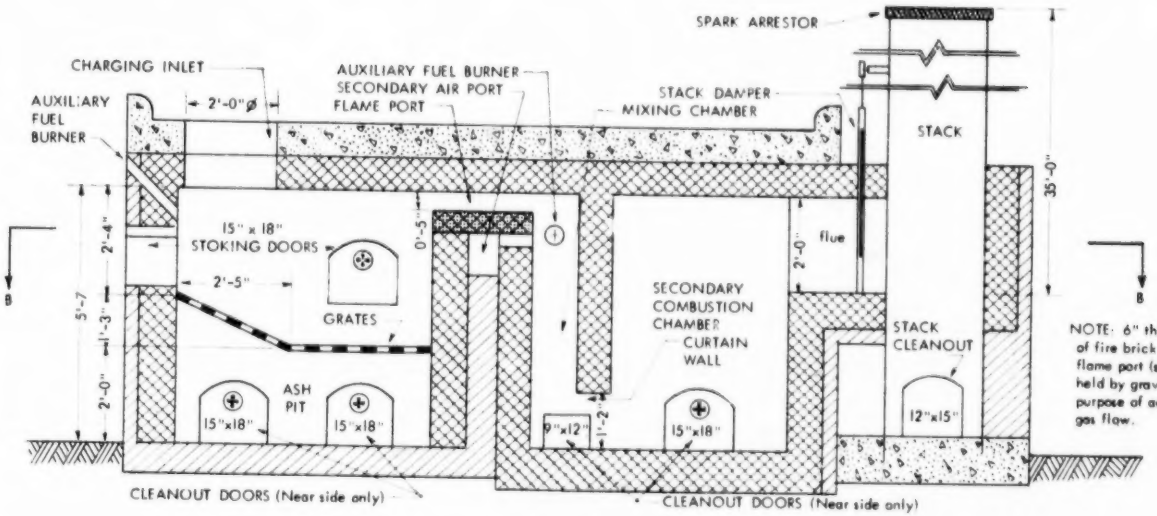
$$0.25 = 0.0084\ H - 0.00132\ H$$

$$0.25 = .00708H$$

$$H = \frac{0.25}{.00708} = 35' - 0''$$ to the nearest ft.

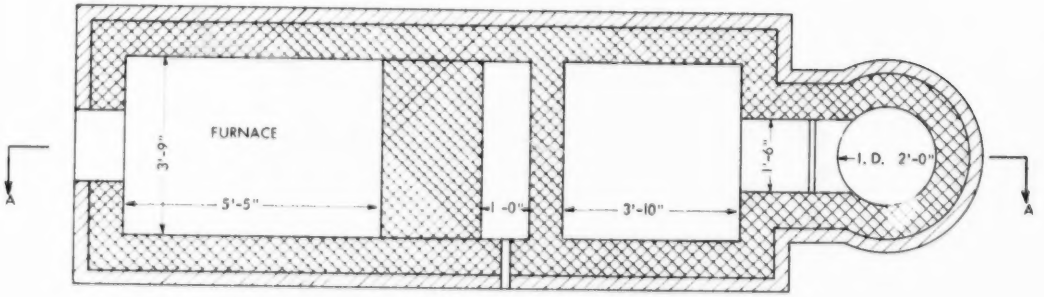
Assuming that there is no obstacle higher than 35' - 0", this is a reasonable chimney height.

Use steel chimney -- 2' - 0" in diameter, and 35' - 0" high.



SECTION A-A

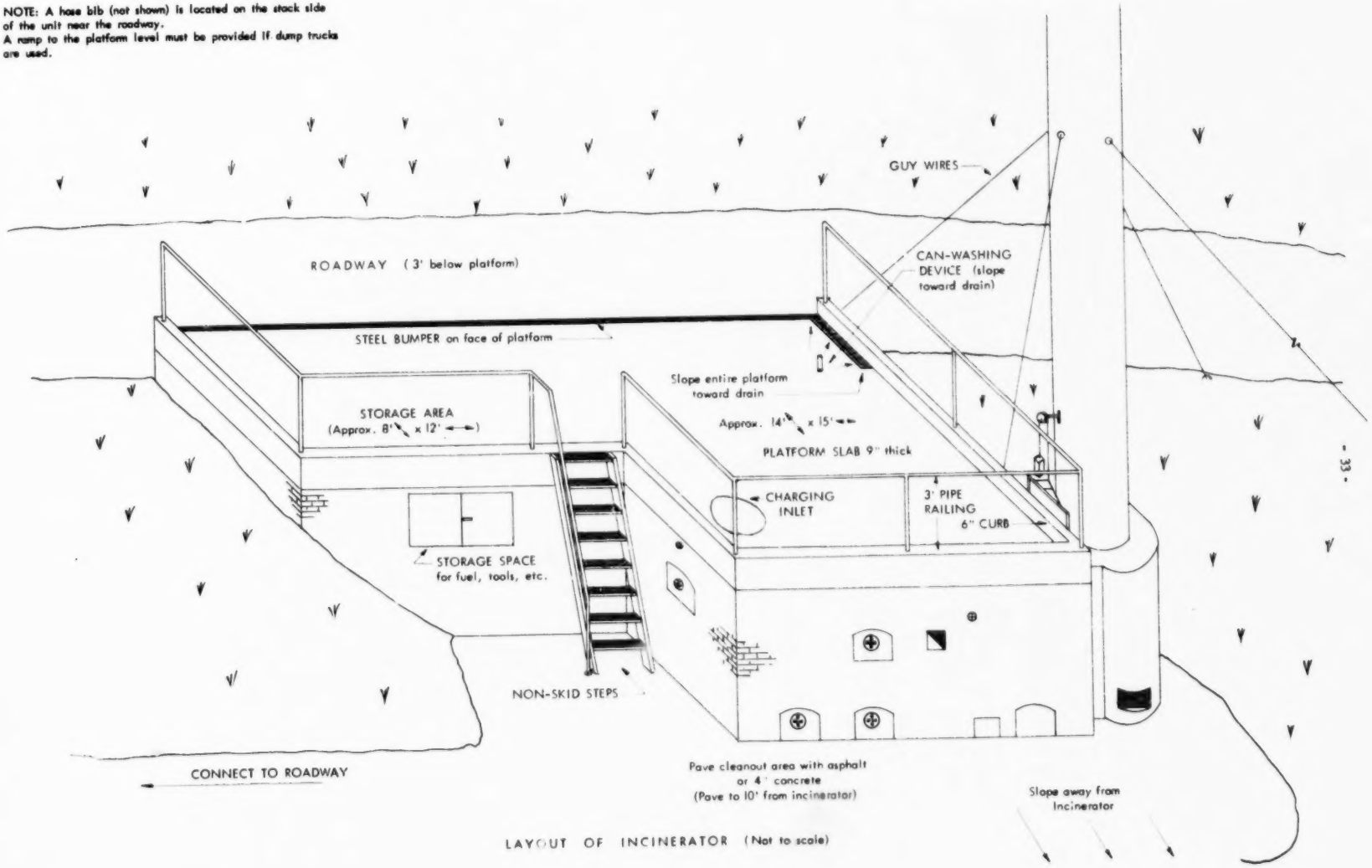
- Facing Brick
- Refractory Brick
- Reinforced Concrete



SECTION B-B

DIAGRAM OF INCINERATOR (Not to scale)

NOTE: A hose bib (not shown) is located on the stack side of the unit near the roadway.
A ramp to the platform level must be provided if dump trucks are used.


GUY WIRES
ROADWAY (3' below platform)
CAN-WASHING DEVICE (slope toward drain)
STEEL BUMPER on face of platform
Slope entire platform toward drain
STORAGE AREA (Approx. 8' x 12')
Approx. 14' x 15'
PLATFORM SLAB 9" thick
CHARGING INLET
3' PIPE RAILING
6" CURB
STORAGE SPACE for fuel, tools, etc.
NON-SKID STEPS
CONNECT TO ROADWAY
Pave cleanout area with asphalt or 4" concrete (Pave to 10' from incinerator)
Slope away from Incinerator

LAYOUT OF INCINERATOR (Not to scale)

BIBLIOGRAPHY

1. Anonymous, "Municipal Incineration," Sanitary Engineering Research Project, University of California, Technical Bulletins No. 5 and 6, 1951.

2. Doolittle and Zerban, Engineering Thermodynamics, International Textbook Company.

3. Foster, William S., "Incinerator Design," The American City, February and March 1954.

4. Greeley, Samuel A., "Background of Design Criteria for Municipal Incinerators -- The Designer's View," A. S. M. E., 1956.

5. Lanigan, Edwin C., "Incinerators -- Design, Construction, Cost, and Location," Public Health News, New Jersey Department of Health, April 1941.

6. Marks, Lionel S., Mechanical Engineers' Handbook, McGraw-Hill Book Company.

7. Rose, A. H., Jr., and Crabaugh, H. R., "Research Findings in Standards of Incinerator Design," in Mallette, F. S., ed., Problems and Controls of Air Pollution, Reinhold, New York, 1955, pp. 95-106.

8. Walker, Lewis, McAdams, and Gilliland, Principles of Chemical Engineering, McGraw-Hill Book Company.

9. Weaver, Leo, "Refuse Sanitation in the National Parks," Public Health Service, April 1955.

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